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13. ABSTRACT *(Maximum 200 words)*

This program had two objectives: to develop selective material processing techniques for both multiple quantum well (MQW) electronic devices and circuits, and to develop design and fabrication techniques for advanced photonic devices and circuits. The ULTRA electronics portion of the program was focused on developing new damage-free etching techniques for nanoscale semiconductor electronic devices; techniques primarily for III-V semiconductors were of interest. The photonics program considered a wide range of materials for photonic integrated devices (PICs) with an emphasis on prototyping methods and novel devices. The successes of the program included new integrated devices, laser prototyping techniques, new design software, and a new fabrication method for single-crystal metal oxides. Technology transfer was realized to two industrial partners.

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SELECTIVE PROCESSING TECHNIQUES FOR ELECTRONIC AND OPTO-ELECTRONIC APPLICATIONS: QUANTUM-WELL DEVICES AND INTEGRATED OPTIC CIRCUITS

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Table of Contents

I. Introduction

This program had two objectives: to develop selective material processing techniques for both multiple quantum well (MQW) electronic devices and circuits, and to develop design and fabrication techniques for advanced photonic devices and circuits. The ULTRA electronics portion of the program was focused on developing new damage-free etching techniques for nanoscale semiconductor electronic devices; techniques primarily for III-V semiconductors were of interest. The photonics program considered a wide range of materials for photonic integrated devices (PICs) with an emphasis on prototyping methods and novel devices.

II. Photonics

Overview

In the photonics area, we accomplished the key objective of designing and implementing two rapid prototyping systems based on photoresist patterning, and direct photochemical etching, for use in fabricating integrated optical circuits. Two new pattern writing systems were developed, aided by a DURIP grant, which employ precision stages and sophisticated control software developed in our lab. In addition, with the second writing system we have developed a new capability for waveguide patterning via negative photoresist. We have used this patterning capability along with both wet and dry chemical etching (CAIBE) to produce low loss waveguides and bends. With these two systems we have been able to investigate several novel device concepts. For example, using the laser-induced wet etching system we have fabricated a novel high speed pulse rate multiplier which employs a unique depth-tapered adiabatic y-branch in its design; while with the laser lithography system we fabricated a novel MMI-based variable power splitter.

These tools have been coupled with our CAD design and simulation software, and our testing facilities to form a complete prototyping cycle. For example, we have compared our experimentally measured Mach-Zehnder modulator performance with that based on numerical simulation. This has involved a careful correlation of 3-D beam propagation simulation (using an accurate index profile given by the etch profile in the GaAs layer), a 2-D PICES simulation of the electronic field/electro-optical response, and our measured optical response. The results indicate that our modeling tools are quite excellent. Both the software and the prototyping system were subsequently "tech-transferred" to AlliedSignal for use in polymer device fabrication.

As mentioned above we have focused on applying these prototyping systems to the development of several new photonic devices. These have included, for example, variable power splitters based on bent multimode interference structures, a TE/TM polarization splitter, and a multistage Mach-Zehnder wavelength filter PIC. Each of these are described briefly below; more complete presentations are seen in the published papers listed below. In addition, the section IX on published papers lists many other publications on other device work.

Specific Devices

a.) Active Polarization Splitter

A tunable TE/TM polarization splitter, based on a Mach-Zehnder interferometer with an electro-optic switched mode sorter was designed and fabricated in GaAs-AlGaAs. The device used new symmetric and asymmetric Y-branches employing height-tapered waveguides to achieve power splitting and mode sorting, respectively, in the interferometer. The device had an extinction ratio of ~ 20 dB and an excess loss less than 1.5 dB for both TE and TM polarized light. The device could be reconfigured by voltage tuning for operation at either 1.3- or 1.55-μm wavelengths.

b.) Optical Delay Line for Pulsed Demultiplexing

An integrated, cascaded, asymmetric GaAs/AlGaAs Mach-Zehnder (MZ) interferometer, for use in wavelength filtering and time-domain multiplexing, has been designed, fabricated, and tested. This device employs several new passive components, including height-tapered Y-branches, for uniform splitting and recombining, and index-tailored waveguide bend is designed with a predistorted index profile for minimizing both transition loss and radiation loss which were developed using the unique design and prototyping tools developed under this contract. The circuit is fabricated with a resistless, light-induced local etching technique, which enables rapid iterative fabrication of the device geometry to achieve the desired operating path delays. Acting as a wavelength filter, the fabricated device has a - 24.3dB minimum-to-maximum extinction ratio and a -10.5 dB side-lobe suppression ratio. Acting as a pulse-rate multiplexer, the device generates a four-pulse train with a 10-ps pulse-to-pulse separation and an amplitude uniformity of 80% for each input pulse.

c.) Novel MMI Power Splitter

A new bent multimode interference-based variable power splitter in GaAs-AlGaAs has been designed and fabricated and uses an internal phase shift to control the power splitting. Simulations were used to investigate sensitivities of the design geometry. The device tests indicate that the device's design splitting ratio performance is relatively fabrication tolerant.

New Fabrication Technology

We have developed a new technique of crystal-ion slicing to enable lift off a free-standing slice of $LiNbO_3$. Deep-ion implantation is used to create a buried sacrificial layer in single-crystal *c*-cut poled wafers of $LiNbO_3$, inducing a large etch selectivity between the sacrificial layer and the rest of the sample. Nine-micron-thick films of excellent quality are separated from the bulk and bonded to silicon and gallium arsenide substrates. These single-crystal films have the same room-temperature dielectric and pyroelectric characteristics, and ferroelectric transition temperature as single-crystal bulk. A stronger high-temperature pyroelectric response is found in the films. This technology can be used to accomplish heterogeneous integration of thin-film modulators.

References for Further Reading:

J.Z. Huang, R. Scarmozzino, G. Nagy, M.J. Steel and R.M. Osgood, Jr., "Realization of a Compact and Single-Mode Optical Passive Polarization Converter," submitted to IEEE Photon. Technol. Lett. July 28, 1999.

D.S. Levy, K.H. Park, R.Scarmozzino, R.M. Osgood, Jr., C. Dries, P. Studenkov, and S. Forrest, "Fabrication of Ultracompact 3dB 2x2 MMI Power Splitters," IEEE Photon. Technol. Lett. 11, 1009-1011 (1999).

M.H. Hu, J.Z. Huang, K.L. Hall, R. Scarmozzino and R.M. Osgood, Jr., "An Integrated Two-Stage Mach-Zehnder Device in GaAs," J. Lightwave Tech. 16, 1447 (1998).

D.S. Levy, Y.M. Li, R.Scarmozzino, and R.M. Osgood, Jr., "A Multimode Interference-Based Variable Power Splitter in GaAs-AlGaAs," IEEE Photon. Tech. Lett. 9, 1373 (1997).

M.H. Hu, J.Z. Huang, R. Scarmozzino, M. Levy and R.M. Osgood, Jr., "Tunable Mach-Zehnder Polarization Splitter Using Height-Tapered Y-branches," IEEE Photon. Technol. Lett. 9, 773 (1997).

III. Advanced Fabrication for ULTRA Devices

This section of the program was focused on developing new fabrication and diagnostic technology for quantum devices. Our first project investigated pattern transfer of submicron features using magnetron-enhanced reactive ion etching (MIE). We have also set up an electron-beam etching system and have started testing using submicrometer patterned GaAs samples. Photoluminescence and cathodoluminescence were used to study the sidewall damage generated by MIE on 160nm to 1500nm semiconductor boxes in GaAs/$Al_{0.3}Ga_{0.7}As$ quantum wells. It was found that decreasing the ion energy by varying the sample bias results in an *increase* of the near-surface damage of the etched sidewalls. Boxes with diameters down to 30 nm were also etched by MIE on GaAs. Atomic force microscopy has been used to investigate uniformity of the etching. Finally, electron-beam assisted chlorine-etching of GaAs has been studied as a function of temperature, chlorine pressure, electron beam energy and current. Thermal chlorine etching is enhanced by the electron beam at high temperatures. Low-temperature etching has also been observed, and a parametric characterization is presently underway.

Subsequently Columbia initiated a program to study GaSb etching using chemically assisted ion beam techniques (CAIBE). The dry etching of GaSb has remained a relatively unexplored subject, especially given the importance of GaSb-based structures for such novel devices as resonant tunneling diodes. The etch rate was characterized as a function of chlorine flow rate and ion beam density showing good feature morphologies down to 250 nm. Columbia's new electron-beam writing capability was used to pattern the masks for these studies. The study of magnetron-enhanced ion beam etching of GaAs was also continued. In addition,

we have used carbon nanotube atomic force microscopy for the first time to characterize the feature morphology and mask erosion as a function of bias voltage and etch depth.

The final portion of this section included work on developing new diagnostic tools for examining nanoscale etched features. These included both electron and proximal based probes. For example carbon nanotubes were used as tips in atomic force microscopy for a systematic study of dry etching pattern transfer in GaAs. The GaAs samples are patterned via electron beam lithography and then etched using magnetron reactive ion or chemically assisted ion beam processing. The carbon tube proximal probe technique allows diagnosis, in air, of etched features with scale sizes of < 100 nm.

References for Further Reading

G. Nagy, R.U. Ahmad, M. Levy, and R.M. Osgood, Jr. "Chemically Assisted Ion Beam Etching of Submicron Features in GaSb. Appl. Phys. Lett.," 72, 1350 (1998).

G. Nagy, M. Levy, R. Scarmozzino, R.M. Osgood Jr., H. Dai, R.E. Smalley, C.A. Michaels, E.T. Sevy, G.W. Flynn, and G.F. McLane, "Carbon Nanotube Tipped Atomic Force Microscopy for Measurement of <100 nm Etch Morphology on Semiconductors," Appl. Phys. Lett. 73, 529 1998.

J.-L. Lin, M. B. Freiler, M. Levy, D. Collins, T. C. McGill and R. M. Osgood Jr., "Photon-Assisted Cryoetching of III-V Binary Compounds by Cl_2 at 193 nm," Appl. Phys. Lett. 67, 3563 (1995).

R.U. Ahmad, G. Nagy, G. W. Turner, M. J. Manfra, and R. M. Osgood, Jr., "Electron Cyclotron Resonance Plasma Etching of GaSb and GaSb-Based Alloys," to be submitted.

IV. Consultative and Advisory Functions

Advisory interactions with MIT Lincoln Laboratory on laser technology and etching technology and with AlliedSignal on PIC technology.

V. Transitions

An important component of our research has been the transfer of technology to nearby industries. The most important example of this work has been the transfer of our laser writing system design and software for use in AlliedSignal's single-mode passive polymer component program. This research effort, which had both commercial and defense applications, is located in Morristown, NJ. Laser prototyping has been used extensively by AlliedSignal to help initiate the program and to test various device concepts. In addition, a design for an adiabatic coupler was transmitted to AlliedSignal.

During this period, Columbia's software for integrated optics, CAD, *BeamPROP*, became the major software tool for the North American Market. This product allowed the Columbia spin-off RSoft to become a major commercial vendor in photonic software.

VI. New Discoveries, Inventions or Patent Disclosures

Patent: We have developed a new technique of crystal-ion slicing to lift off a free standing slice of $LiNbO_3$ and other optical metal oxides. This can be used for a thin-film $LiNbO_3$ modulator to be heteromounted on, say, a SiO_2/Si PIC. A patent on this technology is currently pending.

VII. Honors/Awards

- Drs. Levy and Scarmozzino were promoted to Senior Research Scientist at Columbia University.
- *BeamProp* was highlighted in an IEEE Spectrum article on optical CAD software.
- Prof. Osgood was designated a Fellow in the American Physical Society.
- Dr. Levy served as the co-chair of the MRS Symposium on Integrated Magneto-Optics, held in San Francisco, CA, March 1998.
- Dr. Levy was also invited as colloquium speaker at the University of California, at Irvine, April, 1998.

VIII. Personnel Supported

Principal Investigator
Dr. Richard M. Osgood, Jr., Higgins Professor

Senior Research Scientists
Dr. Robert Scarmozzino
Dr. Miguel Levy

Current Graduate Research Assistants
Hongling Rao
Juni Fujita

Former Graduate Research Assistants
Dr. Johnny Huang, awarded the Ph.D. in Electrical Engineering (1999)
Thesis title: "Design and Fabrication of Integrated Optical Waveguide Devices"
Boston Consulting

Dr. David S. Levy, awarded the Ph.D. in Electrical Engineering (1998)
Thesis title: "The Design and Fabrication of Integrated Optical Power Splitters"
Lucent

Dr. Martin (Hai) Hu, awarded the Ph.D. in Electrical Engineering (1997)

Thesis title: "Design and Laser-Fabrication of Waveguide Components and Integrated Photonic Circuits"
Corning

Dr. Michael Freiler, awarded the Ph.D. in Electrical Engineering (1995)
Thesis title: "The Application of Photon-Driven Cryoetching to Micro- and Nanostructure Fabrication"
IBM and Sematech

Dr. Louay Eldada, awarded the Ph.D. in Electrical Engineering (1994)
Thesis title: "Laser-Controlled Rapid Prototyping of Photonic Integrated Circuits"
AlliedSignal Corp.

IX. Publications

1. J.Z. Huang, R. Scarmozzino and R.M. Osgood, Jr., "A New Design Approach to Large Input/Output-Number Multimode Interference Couplers and its Application to Low-Crosstalk WDM Routers," Photon. Technol. Lett. 10, 1292 (1998).

2. D. S. Levy, R. Scarmozzino, R.M. Osgood, Jr., "Size Reduction in Multimode Interference-Based NxN Couplers Using a Tapered Waveguide Geometry," Proceedings of SPIE Photonics West Conference, SPIE 3278, 191 (1998).

3. D. Levy, R. Scarmozzino and R M. Osgood, Jr. "Length Reduction of Tapered NxN MMI Devices," IEEE Photon. Technol. Lett. 10, 830 (1998).

4. G. Nagy, R.U. Ahmad, M. Levy, and R.M. Osgood, Jr. "Chemically Assisted Ion Beam Etching of Submicron Features in GaSb. Appl. Phys. Lett.," 72, 1350 (1998).

5. G. Nagy, M. Levy, R. Scarmozzino, R.M. Osgood Jr., H. Dai, R.E. Smalley, C.A. Michaels, E.T. Sevy, G.W. Flynn, and G.F. McLane, "Carbon Nanotube Tipped Atomic Force Microscopy for Measurement of <100 nm Etch Morphology on Semiconductors," Appl. Phys. Lett. 73 , 529 1998.

6. M.H. Hu, J. Z. Huang, K. L. Hall, R. Scarmozzino and R.M. Osgood, Jr., "An Integrated Two-Stage Cascaded Mach-Zehnder Device in GaAs," J. Lightwave Technology 16, 1447 (1998).

7. J. Z. Huang, M. H. Hu, J. Fujita, R. Scarmozzino and R. Osgood Jr., "High Performance Metal-Clad Multimode Interference (MMI) Devices for Low-Index-Contrast Material System," IEEE Photon. Tech. Lett. 10, 561 (1998).

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9. T.A. Ramadan, R. Scarmozzino and R. M. Osgood Jr., "Adiabatic Couplers: Design Rules and Optimization," J. Lightwave Tech. 16, 277 (1998).

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11. J. Fujita, M. Levy, R. Scarmozzino, and R.M.Osgood, Jr., "Integrated Multistack Waveguide Polarizer," Photon. Technol. Letts. 10 93, (1998).

12. M.H. Hu, J.Z. Huang, R. Scarmozzino, M. Levy and R.M. Osgood, Jr., "Tunable Mach-Zehnder Polarization Splitter Using Height-Tapered Y-branches," IEEE Photon. Technol. Lett. 9, 773 (1997).

13. D. S. Levy, Y. M. Li, R. Scarmozzino and R. M. Osgood Jr., "A Multimode Interference-Based Variable Power Splitter in GaAs-AlGaAs," IEEE Photonics Technology Letters 9, 1373 (1997).

14. I. Ilić, R. Scarmozzino, R.M. Osgood, Jr., J.T. Yardley, K.W. Beeson, M.J. McFarland, and K.M.T. Stengel, "Photopatterned Polymer Multimode 8x8 Star Couplers: Comparative Design Methodologies and Device Measurements," IEICE Trans. Commun. E80-B (1997).

15. M. Levy, R.M. Osgood, Jr., A. Kumar, and H. Bakhru, "Epitaxial Liftoff of Thin Oxide Layers: Yttrium Iron Garnets onto GaAs," Appl. Phys. Lett. 71, 2617 (1997).

16. M. Levy, H. Hegde, F. J. Cadieu, R. Wolfe, V. J. Fratello and R. M. Osgood Jr., "Integrated Optical Isolators with Sputter-Deposited Thin-Film Magnets," Photonics Tech. Lett. 8, 903 (1996).

17. I. Ilić, R. Scarmozzino, and R.M. Osgood, Jr., "Investigation of the Padé Approximant-Based Wide-Angle Beam Propagation Method for Accurate Modeling of Waveguiding Circuits," IEEE J.Lightwave Tech. 14, 2813 (1996).

18. M. Levy, H. Hegde, F.J. Cadieu, R. Wolfe, V.J. Fratello, and R.M. Osgood, Jr., "Integrated Optical Isolators with Sputter-Deposited Thin-Film Magnets," Photon. Technol. Lett. 8, 903 (1996).

19. M.B. Freiler, M.C. Shih, S. Kim, M. Levy, I.P. Herman, R. Scarmozzino, and R.M. Osgood, Jr., "Pattern Transfer and Photoluminescence Damage Assessment of Deep-Submicrometer Features Etched by Photon-Induced Cryoetching," Appl. Phys. A63, 143 (1996).

20. E. Kim, G. Whitesides, M.B. Freiler, M. Levy, J.-L. Lin, and R.M. Osgood, Jr., "Fabrication of Micrometer-Scale Structures on GaAs and GaAs/AlGaAs Quantum Well Material Using Microcontact Printing," Nanotechnology 7, 266 (1996).

21. M. C. Shih, M. Hu, M. B. Freiler, M. Levy, R. Scarmozzino, R. M. Osgood Jr., I.W. Tao, and W.I. Wang, "Fabrication of an InGaAs Single Quantum Well Circular Ring Laser by Direct Laser Patterning," Appl. Phys. Lett. 66, 2608 (1995).

22. J.-L. Lin, M. B. Freiler, M. Levy, D. Collins, T. C. McGill and R. M. Osgood Jr., "Photon-Assisted Cryoetching of III-V Binary Compounds by Cl_2 at 193 nm," Appl. Phys. Lett. 67, 3563 (1995).

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24. L. Eldada, R. Scarmozzino, R. M. Osgood, Jr., D. C. Scott, Y. Chang and H. R. Fetterman, "Laser-Fabricated Delay Lines in GaAs for Optically-Steered Phased-Array Radar," J. Lightwave Tech. 13, 2034 (1995).

25. M. B. Freiler, G. F. McLane, S. Kim, M. Levy, R. Scarmozzino. I.P. Herman, and R. M. Osgood Jr. "Luminescence Properties of Submicron Features Fabricated by Using Magnetron Reactive Ion Etching with Different Sample Biases," Appl. Phys. Lett. 67, 3883 (1995).

26. R. Scarmozzino, R. M. Osgood Jr., L. Eldada, M. Hu, Z. Huang, D. Levy, P. Marbach and M. Levy, "Rapid Design and Fabrication of New Photonic Integrated Circuits for Lightwave Systems," Proceedings of SPIE Photonics East Conference, 2613, 60 (1995).

27. J. S. Shor, A. D. Kurtz, I. Grimberg, B. Z. Weiss and R. M. Osgood Jr., "Dopant Selective Etch-Stops in 6H and 3C," J. Appl. Phys. 81, 1546 (1995).

Presentations

1. LEOS'98 Conference, Walt Disney World Swan Hotel, Orlando, FL, Dec 1- 4, 1998. "Bi-directional Beam Propagation Method for Problems with Multiple Dielectric Interfaces, " H. Rao, R. Scarmozzino, and R.M. Osgood, Jr.

2. LEOS '98 Conference, Walt Disney World Swan Hotel, Orlando, FL, Dec 1- 4, 1998. "A New Design Approach to Large Input/Output-Number Multimode Interference (MMI)," J.Z. Huang, R. Scarmozzino, and R.M. Osgood, Jr., AFOSR/ DARPA.

3. American Vacuum Society Meeting. Baltimore Convention Center, Baltimore, MD, November 2-6, 1998. " Chemically Assisted Ion-Beam Etching of Submicrometer Features in GaSb-based Quantum Wells," G. Nagy, R.U. Ahmad, M. Levy, R.M. Osgood, Jr., M.J. Manfra, and G.W. Turner.

4. Michigan Technological University, September 10, 1998.
"Crystal Ion Slicing for Integrated Circuit Applications," (invited talk) Miguel Levy.

5. City College of NY, Physics Department Colloquium, September 9, 1998.

"Crystal Ion Slicing for Integrated Photonics," (invited talk) Miguel Levy.

6. Dartmouth University, Hanover, New Hampshire, May 28, 1998
"New Chip Technologies for Optical Communications: Materials, Thin-Films, and Design Tools," Richard M. Osgood, Jr.

7. OSA IPR'98, Victoria British Columbia Canada, March 30-April 3, 1998
"New design Procedure for Large-Input/Output-number Multimode Interference (MMI) couplers and Application to WDM Routers," J.Z. Huang, R. Scarmozzino and R.M. Osgood, Jr.

8. Materials Research Society Symposium, San Francisco, CA, April 13-17, 1998
Integrated Magneto-Optics - Materials and Devices,
"Crystal Ion Slicing of Magnetic and Ferroelectric Oxide Films," M. Levy, R.M. Osgood, Jr., A. Kumar, H. Bakhru

9. SPIE Photonics West '98/Optoelectronics '98, San Jose, CA, January 23-24, 1998
"Size Reduction in Multimode Interference-Based NxN Couplers Using a Tapered Waveguide Geometry," D. Levy, R. Scarmozzino, Y. Li and R.M. Osgood, Jr.

10. SPIE LEOS 1997 Lasers and Electro-Optics Society 1997 Annual Meeting, San Francisco, CA, November 10-13, 1997
"Simulation and Computer Aided Design of Large-Scale Photonic Integrated Circuits Using the Beam Propagation Method (BPM)," (invited talk) R. Scarmozzino and R.M. Osgood, Jr.

11. SPIE LEOS 1997 Lasers and Electro-Optics Society 1997 Annual Meeting, San Francisco, CA, November 10-13, 1997
"A New Design for Ultracompact Multimode Interference-Based 2x2 Couplers," D. S. Levy, R. Scarmozzino, Y. M. Li and R. M. Osgood, Jr.

12. SPIE LEOS 1997 Lasers and Electro-Optics Society 1997 Annual Meeting, San Francisco, CA, November 10-13, 1997
"Computer Aided Design of Large-Scale Photonic Integrated Circuits," R. Scarmozzino and R.M. Osgood, Jr.

13. Optical Society of America Annual Meeting, Long Beach, CA, October 12-17, 1997
"Epitaxial Liftoff of Single-Crystal Magnetic Garnet Waveguide Films," M. Levy, R.M. Osgood, Jr., A. Kumar, H. Bakhru

14. IEEE/LEOS 1997 Summer Topical Meetings, The Queen Elizabeth Hotel at Montreal, Quebec, Canada, August 11-15, 1997
WDM Components Technology, "High Performance Metal-Coated Multimode Interference (MMI) Devices for WDM Applications," J. Huang, M.H. Hu, J. Fujita, R. Scarmozzino, and R.M. Osgood, Jr.

15. CLEO QELS'97 Annual Meeting, 1997, Baltimore, MD, May 18-23, 1997

"Epitaxial Liftoff of Crystalline Magnetic Garnet Waveguide Films," M. Levy, R.M. Osgood, Jr., A. Kumar, and H. Bakhru

16. Optical Society of America, Stockholm, Sweden, April 2-4, 1997
1997 European Conference on Integrated Optics, "A Multi-Mode Interference-based Variable Power Splitter in GaAs," D.S. Levy, Y.M. Li, R.Scarmozzino, and R.M. Osgood, Jr.

17. SPIE Photonics West '97, San Jose, February 8-14, 1997
Optoelectronic Interconnects and Packaging IV, "Design and Fabrication of Passive Optical Polymer Waveguide Components for Multimode Parallel Optical Links," Dr. Robert Scarmozzino, R.M. Osgood, Jr., L. Eldada, J.T. Yardley, Y. Liu, J. Bristow, J. Stack, J. Rowlette and Y.S. Liu

18. LEOS '96, Boston, MA, November 18-21, 1996
"Electronically Tunable Mach-Zehnder Polarization Splitter," M.H. Hu, J.Z. Huang, R. Scarmozzino, M. Levy, and R.M. Osgood, Jr.

19. LEOS '96, Boston, MA, November 18-21, 1996
"Sputtered-Magnet Mach-Zehnder Waveguide Isolator," M. Levy, M.H. Hu, R. Scarmozzino, and R.M. Osgood, Jr.

20. Rice University, Rice University, Houston, TX, November 1, 1996
"Quantum Confinement of Surface Electrons," (invited talk) Richard M. Osgood, Jr.

21. DARPA/ETO 1996 Optoelectronics Program Review, Lake Buena Vista, FL, October 7-10, 1996
"Novel Processing Techniques for Electronic and Optoelectronic Applications: QW Devices and Integrated Optic Circuits," R.M. Osgood, Jr. and R. Scarmozzino

22. DARPA Ultra Electronics Program Review, Estes Park, CO, October 6-10, 1996.
"Novel Processing Techniques for Electronic and Optoelectronic Applications: Quantum-Well Devices and Integrated Optic Devices and Circuits (Ultra Microelectronics portion only)," R.M. Osgood, Jr. and M. Levy

23. University of Maryland, Baltimore, MD, September 21, 1996
"Photonic Integrated Circuits: Devices, Design, and Fabrication," (invited talk) R.M. Osgood, Jr.

24. Gordon Research Conference, Henniker, New Hampshire, June 23, 1996
Nanostructure Fabrication, "Cathodoluminescence and Photoluminescence Study of Submicron Features Fabricated by Magnetron Reactive Ion Etching," Miguel Levy (poster, not talk).

25. OSA Topical Meeting, Boston, MA, April 29 - May 1, 1996
Integrated Photonics Research, "Use of Higher Order Padé Approximants for Efficient Simulation of Wide-Angle Waveguides with Step-Index Profile," I. Ilić, R. Scarmozzino and R.M. Osgood, Jr.

26. OSA Topical Meeting, Boston, MA, April 29-May 1, 1996
Integrated Photonics Research, "Novel Optical Pulse-Rate Multiplier in GaAs Using Height-Tapered 1x4 Splitters," M. Hu, T.G. Chang, D.S. Levy, J.Z. Huang, I. Glesk, R. Scarmozzino, M. Levy, R.M. Osgood, Jr., and P. Prucnal

27. SPIE Photonics East, Philadelphia, PA, October 24, 1995
Conference on Emerging Components and Technologies for All-Optical Photonic Systems, "The Design and Prototyping of Large Area PIC's," R. Scarmozzino and R. M. Osgood, Jr.

28. 42nd AVS National Symposium, Minneapolis, MN, October 16-20, 1995
"Low Sidewall Damage Submicrometer-Scale Features Fabricated by Magnetron Reactive Ion Etching," M.B. Freiler, S. Kim, M. Levy, R. Scarmozzino, I.P. Herman, G.F. McLane and R.M. Osgood, Jr.

29. Gordon Research Conference, Chemistry of Electronic Materials,
Andover, NH, July 30 - August 4, 1995
"Characterization of Photon-Assisted Cryoetching of III-V Materials by Cl_2," J.-L. Lin, M.C. Shih, M.B. Freiler, M. Levy and R.M. Osgood, Jr.

30. MIT Department of Materials Science & Engineering, Electronic Materials Thursday Seminar, Cambridge, MA, March 16, 1995
"Advanced Etching Technologies for Integrated Optics and Quantum-Confined Structures," R M. Osgood, Jr.

31. OSA Integrated Photonics Research Topical Meeting, Dana Point, CA, February 23, 1995, "Wide-angle Beam Propagation Modeling of Variable-Angle Photonic Circuits," I. Ilić, R. Scarmozzino, and R. M. Osgood, Jr.